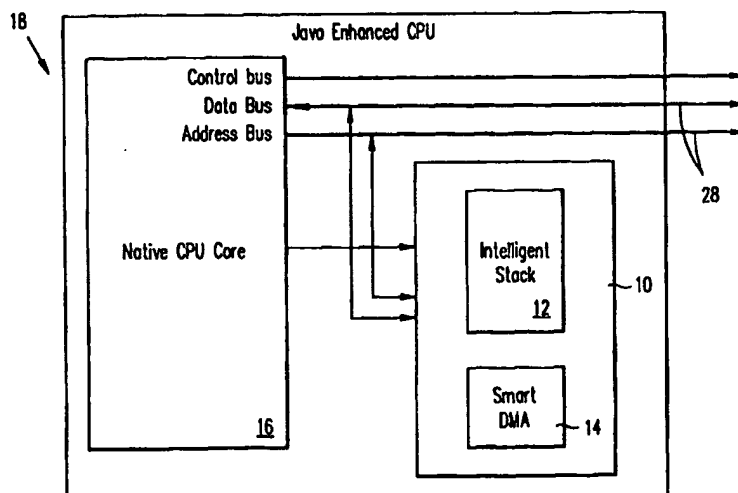




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<b>(21) International Application Number:</b> PCT/US97/20980  <b>(22) International Filing Date:</b> 13 November 1997 (13.11.97)  <b>(30) Priority Data:</b> 60/030,688                      13 November 1996 (13.11.96)      US  <b>(71) Applicant (for all designated States except US):</b> PARAN, Arik [US/US]; 866 Helena Drive, Sunnyvale, CA 94087 (US).  <b>(71)(72) Applicant and Inventor:</b> RAZ, Yair [IL/US]; 1575 Lewiston Drive, Sunnyvale, CA 94087 (US).  <b>(74) Agents:</b> HAMRICK, Claude, A., S. et al.; Oppenheimer Wolff & Donnelly LLP, Suite 600, Ten Almaden Boulevard, San Jose, CA 95113 (US).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

**(54) Title:** REAL TIME PROGRAM LANGUAGE ACCELERATOR**(57) Abstract**

A program language accelerator core (10) operating in conjunction with a program language accelerator software (34) in a computer (20) for optimizing the operation of Java™ program code in a native CPU (16) processor. An intelligent stack (12) has a plurality of memory areas (52, 54, 56 and 58) in a memory map (50) mapped such that particular operations are performed depending upon which of the memory areas (52, 54, 56 or 58) the native CPU (16) addresses. When the program language accelerator software (34) translates the Java™ code into the native code of the native CPU (16), optimization is provided by directing read and write operations to the appropriate area in the memory map (50) such that it is not necessary to include a separate instruction regarding how the data being written is to be handled.

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**Specification****REAL TIME PROGRAM LANGUAGE ACCELERATOR****TECHNICAL FIELD**

The present invention relates to the field of computer processing and more specifically to the real time interpretation and operation of computer code using a combination of unique hardware and software. The predominant current usage of the present inventive real time program language accelerator is in the execution of Java™ code wherein it is desirable to be able to run such code at high execution speed on a variety of different processors.

**BACKGROUND ART**

It is known in the art to provide interpreters for converting higher level computer languages into machine readable code in near real time. However, such interpreters must necessarily slow down the operation of the program being run at least at some point in during the loading and running of the program. In particular, regarding the Java™ program language, the several available solutions for running Java™ programs, including the "Java™ Virtual Machine" are software based programs which require execution in order to accomplish their tasks.

It would be beneficial to have a method and/or means for running Java™ code on any available type of processor. Also, it would be beneficial to have some method and/or means for processing the Java™ code such that it will actually run faster than it otherwise would, or at least that would not slow down the overall process of interpreting and running the Java™ code. However, to the inventor's knowledge, no system for accomplishing these objectives has existed in the prior art. Indeed, although software solutions such as the Java™ Virtual machine do attempt to optimize the operation of the code, a limitation has been the characteristics of the particular processor and system on which the code is to be run.

**DISCLOSURE OF INVENTION**

Accordingly, it is an object of the present invention to provide a method and means for easily running a non-native program language on virtually any type of processor.

It is still another object of the present invention to provide a method and means for accelerating the operation of Java™ program code.

It is yet another object of the present invention to provide a method and means for translating and executing Java™ code which is easily implemented in hardware.

It is still another object of the present invention to provide a method and means for translating and executing Java™ code which will not detract from the ability of the computer system to execute non- Java™ code.

Briefly, the preferred embodiment of the present invention is an integrated circuit "program language accelerator core" which can be embodied as part of a CPU chip, on a separate chip, or even on a separate board. The program language accelerator core has a dedicated hardware stack memory for directly providing the stack memory which is required to be either present or emulated for the execution of Java™ code. A direct memory access ("DMA") controller is also provided for shifting data into and out of the stack memory as overflow and underflow conditions (or other specified conditions) occur. A software portion of the invention translates the Java™ code into a machine native language code, and also optimizes the code to perform unique inventive functions as required, such as writing to a memory address which is predetermined to perform specified functions. In this manner, operations that might otherwise take several clock cycles can be performed in a single (or at least fewer) clock cycles.

An advantage of the present invention is that the speed of execution of Java™ code is greatly increased.

A further advantage of the present invention is that Java™ code can be readily executed on essentially any type of processor.

Yet another advantage of the present invention is that it can be easily and inexpensively implemented such that even affordably priced computers can be optimized for the execution of Java™ code.

Still another advantage of the present invention is that it is not difficult or expensive to adapt to new types of processors such as might become available.

These and other objects and advantages of the present invention will become clear to those skilled in the art in view of the description of the best presently known mode of carrying out the invention and the industrial applicability of the preferred embodiment as described herein and as illustrated in the several figures of the drawing.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a block diagram of an integrated circuit having thereon a program language accelerator core according to the present invention;

Fig. 2 is a block diagram showing an example of how an CPU enhanced according to the present invention might be integrated into a computer system;

Fig. 3 is a more detailed block diagram of the intelligent stack of Fig. 1;

Fig. 4 is a memory map of the intelligent stack depicted in Figs. 1 and 3;

Fig. 5 is a flow diagram of one aspect of the inventive process;

Fig. 6 is a flow diagram of a value push operation according to the present invention;

Fig. 7 is a flow diagram of a value pop operation according to the present invention;

Fig. 8 is a flow diagram of a constant push operation according to the present invention;

Fig. 9 is a flow diagram of an arithmetic operation according to the present invention;

Fig. 10 is a flow diagram of a local variables load operation according to the present invention;

and

Fig. 11 is a flow diagram of a local variables store operation according to the present invention.

### **BEST MODE FOR CARRYING OUT INVENTION**

The best presently known mode for carrying out the invention is a real time accelerator core. The inventive real time accelerator core is depicted in a block diagrammatic view in Fig. 1 and is designated therein by the general reference character 10.

The real time accelerator core 10 has an intelligent stack 12 and a smart DMA controller 14. The real time accelerator core 10 will allow real time translation and execution of Java™ object code by any target native CPU 16 such that the native CPU can execute Java™ programs without any additional software based translation or interpretation in a much higher performance mode (compared to the standard Java™ interpreter or JIT compilers). It should be noted that, in the example of Figure 1, the program language accelerator core 10 and the CPU are embodied on a single CPU chip 18 although, as previously discussed herein, this is not a necessary aspect of the invention.

Figure 2 is a diagrammatic example of a typical computer configured for operation with the CPU chip 18 having therein the program language accelerator 10. It will be noted that the connections of the CPU chip 18 within the computer are not significantly different from those of a comparable conventional prior computer (not shown). A data bus 22, an address bus 24 and a control bus 26 are each provided with the appropriate data paths 28 for communicating with the CPU chip 18, a (RAM) memory 30 and an I/O section 32.

The data bus 22 is the native CPU data bus. The width of the data bus 22 should be the natural data bus width of the native CPU 16 (8, 16, or 32 bits). The interface logic in the program language accelerator core 10 will take care of any data width related tasks. The address bus 24 is the native CPU address bus. The width of the address bus 24 should be the natural address bus width of the native CPU 16. The control bus 26 will carry the several control signals that can be found in any CPU: Clock, Reset, Read and Write, interrupt lines, bus request, etc.

It should be noted that the example of Figure 2 is provided only to show the context in which inventive program language accelerator core 10 might be used, and is not intended to disclose an inventive aspect of the invention. In operation, the memory 30 will contain the required initialization software for the native CPU 16 (Figure 1), an operating system (if used), I/O device drivers or control code, as well as a program language accelerator software 34 the functions of which will be discussed in

greater detail hereinafter. In addition, the memory 30 can contain any compiled Java™ code required (specific custom class libraries, for example).

Depending on the end user's application, the computer 20 equipped with the inventive program language accelerator core 10 and the program language accelerator software 34 can execute any Java™ code which already exists in non-volatile memory, or load it through the applicable I/O devices (communication ports, disk, etc.).

The program language accelerator core 10 takes advantage of the fact that the Java™ Virtual Machine is a stack based machine emulation, and most stack operations on a contemporary CPU (such as the native CPU core 16 of Figure 1) take more than 1 clock cycle to complete. The intelligent stack 12 is essentially a large virtual cache for the Java™ Virtual Machine stack. The DMA controller 14 (Figure 1) keeps the cache consistent if a stack overflow or underflow would occur due to the limited size of the actual cache, as will be discussed in greater detail hereinafter.

Figure 3 is a more detailed block diagram of the intelligent stack 12 previously discussed herein in relation to Figure 1. In the view of Figure 3 it can be seen that the intelligent stack 12 has a simple internal arithmetic logic unit ("ALU") which allows the pushing of constants as defined by the Java™ Virtual Machine specification, along with the operations that update the tops of the stack such as *iadd* or *iinc*, all of which will be familiar to one skilled in the implementation of the Java™ Virtual Machine. A cache 38 is the actual cache memory within the intelligent stack. A stack controller 40 has a stack pointer 42 and stack pointer next 44 such as are found in conventional stack control devices. A conventional decoder 46 is provided for decoding addresses and instructions and an output MUX 48 provides output from the source within the intelligent stack 12 which is appropriate to the operation.

The intelligent stack 12 is a 64 x 32-bit register file configured to be used as a stack. The intelligent stack 12 is memory mapped into the native CPU 16 memory address space, and allows the native CPU 16 fast stack operation (push, pop), and also random access to any one of the registers. The intelligent stack 12 provides circuitry for automatic stack overflow/underflow detection. The smart DMA controller 14 is configured to read and write the content of the entire intelligent stack 12 to or from the memory 30, such as when it is required to shift between different tasks. The smart DMA controller 14 also corrects potential stack overflow or underflow by temporarily storing any excess of data from the intelligent stack 12 to the memory 30. The smart DMA will dump a block of words to main memory 30 when the stack approaches overflow (on Push operation), or will load a block of words from main memory 30 when the stack approaches underflow (on Pop operation). The smart DMA controller can load a local variable from main memory 30 (on Variable Load miss), store a local variable to main memory 30 (on Variable Store miss), dump the entire cache 38 to main memory 30 to prepare for a context switch, or load the entire cache 38 from memory 30 to perform a context switch. The smart DMA can also optionally be used to accelerate thread context switching by moving data into and out of the cache 38, as required.

It should be noted that the inventive program language accelerator 10 could be made to operate without the smart DMA controller 14, although the addition of the smart DMA controller 14 does significantly increase the usefulness and functionality of the program language accelerator 10.

Since Java™ operations are based on a stack machine architecture, the program language accelerator software 34 is required to perform only a very simple translation of the Java™ code to native CPU code. The translation is done using the support language accelerator software 34, preferably as the Java™ code is loaded. Optimization according to the present invention will be provided during the translation by methods including the present inventive method of providing that certain operations be directed to certain memory addresses, as will be discussed in more detail hereinafter. Since the native CPU 16 does not need to deal with stack management (which is handled by the intelligent stack 12), very high speed execution of Java™ programs is possible.

According to the present invention data will come from the data bus 22 and flow onto the top of the stack (much as a conventional stack operation) or else will have an arithmetic operation including the value at the top of the stack and then replace or push onto the top of the stack. Unique to the present invention is the fact that all of the operations are determined by the addresses used. The intelligent stack 12 occupies four times the address space of the cache 38. That is, four times the number of addresses are mapped to memory of the CPU chip 18 than are required to fully address all of the actual memory locations in the intelligent stack 12. The size of the cache in the best presently known embodiment 10 of the present invention is 64 words so the intelligent cache 12 occupies 256 locations in this embodiment.

Figure 4 is a simple memory map 50 of the memory addresses occupied by the intelligent stack 12. In the view of Figure 4 it can be seen that the memory map 50 has a first area 52, a second area 54, a third area 56 and a fourth area 58. Of these, only the first area 52 relates directly to the physical cache 38. A complete address 60 for addressing the memory map 50 will have two select area bits 62 for selecting which of the areas 52, 54, 56 or 58 is to be addressed and an 8 bit select byte 64 for addressing specific data locations within the respective areas. Since each of the four areas 52 allows different operations to be executed by reading or writing to an address therewithin, the upper two address bits (the select area bits 62) of program language accelerator core 10 determines which area 52, 54, 56 or 58 is addressed, and so determines the major operation mode of the device.

Table 1, below, provides a general description of the operations which are performed when the native CPU 16 addresses each of the four areas 52, 54, 56 and 58 of the memory map 50.

TABLE 1

Upper Address Bits	program language accelerator core Major Operation Areas
00	Direct access to hardware stack (cache) data.
01	Access to Configuration and Control Registers
10	Read: Pop value from stack. Write: Push value or constant into stack (depending upon address within the area.

11	Read: Undefined. Write: Replaces TOS with the required operation's result. Operation is performed on TOS and the data written. Operation depends upon address within the area.
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Briefly, values written to the first area 52 of the memory map 50 may be directly written or read by the native CPU 16 at the base address of the device. The second area 54 is used for the configuration and control registers. The third area 56 is used for push and pop operations. The fourth area 58 is used for arithmetic operations that replace the value at the top of the stack. The decoder 46 looks at the incoming address request and thereby automatically determines the operation, the correlation between address and operation having been previously established during translation by the program language accelerator software 34. The data busses and timing are generic single cycle busses where the address, read and write signals are valid on the clock, and read data is expected by the following clock.

Figure 5 is a flow diagram 68 depicting the general operation of the computer 20 according to the present inventive method. Whenever the computer 20 is restarted, specific initialization is done by the native CPU 16: Setting up hardware devices, initializing the operating system (if used), executing any required startup program, and so on. These programs are written in the native CPU 16 language (e.g. instruction set) and are executed by the native CPU 16 directly. These are done without any connection to Java™ and/or program language accelerator core 10. Also, in a set up internal registers operation 70 the native CPU will initialize memory registers, including those that are set aside for addressing the program language accelerator core 10. This is the initial phase of operation when the user invokes and starts the Java™ Execution Environment. During initialization of the Java™ Virtual Machine, the Java™ Virtual Machine will detect the existence of program language accelerator core 10 and its support software (the program language accelerator software 34), and initializes both of them. Among the various initializations done at this phase, some of the most important are setting the various Configuration Registers of program language accelerator core 10 (as described in herein in relation to the second area 54 of the memory map 50).

Any required native program might then be executed by the computer 20. This is also done directly by the native CPU 16 without any operation required by program language accelerator core 10. (These operations are not shown in the flow diagram 68 of Figure 5, and are mentioned here only to put the flow diagram 68 in the correct context.

When a Java™ class file needs to be executed (either it exists already in memory, or it needs to be loaded from disk or received from a communication line), the Native CPU 16 uses the JVM class loader and the program language accelerator software 34 to load, prepare, perform translation, and start executing the required file. This process is made of several steps which will be describe in details in the following sections: In a class file load operation 72, a Java™ class file is loaded. This part is executed entirely by the standard Java™ Virtual Machine code, as described in "The Java™ Virtual Machine



Specification". In a linking and verification operation 74, linking, verification, preparation and resolution are performed conventionally by the Java™ Virtual Machine linker. This part is also executed entirely by the standard Java™ Virtual Machine code.

Following, in a translation operation 76, the native CPU 16 locates the class file's implementation code (e.g. the Java™ Virtual Machine byte code which implements the class), translates it to native instructions, and loads it to an execution area in the memory 30. This part is done entirely by the program language accelerator software 34. The purpose of the translation phase is to convert the Java™ byte code (which was loaded and linked in the previous phases) to the native CPU instruction streams, suitable to operate program language accelerator core 10. Since, as described herein, reading or writing from/to special memory locations invokes all of program language accelerator core 10 operations, the translated native code will mostly contain read and write instructions from/to the various memory areas of program language accelerator core 10. The specific translation of byte code to native code depends on the native CPU that is attached to program language accelerator core 10. The translated code is stored in the memory 30. Once a class file is fully translated, the original byte code image can be discarded, and only the translated native code will be used.

Once the loading process is complete, the native CPU 16 will perform a branch (jump) to the entry point of the translated native code and will start executing the class initialization code, which is now a native program with instruction sequences that take advantage of program language accelerator core 10 dedicated hardware stack and logic, as discussed throughout this disclosure. This is indicated by an execute native code operation 78 in the flow diagram 68 of Figure 5.

Further details of the operation of the inventive method occurring within the execute native code operation 78 will be discussed in relation to additional flow diagrams hereinafter. These operations and respective flow diagrams are as follows: A value push operation 80 (Figure 6) and a value pop operation 82 (Figure 7), both of which relate to operations which occur when the native CPU 16 addresses the second area 54 of the memory map 50 of the intelligent stack 12. A constant push operation 84 (Figure 8) also relates to operations which occur when the native CPU addresses selected locations of the second area 54 of the memory map 50 of the intelligent stack 12. (One familiar with Java™ will recognize that there is no need for an equivalent "constant pop" operation.)

An arithmetic operations 84 flow diagram (Figure 9) describes operations which occur in the program language accelerator core 10 when selected areas of the third area 54 of the memory map 50 are addressed. A local variables load operation 88 (Figure 10) and a local variables store operation 90 (Figure 11) describe these respective functions and will provide more detail about the operation of the smart DMA controller 14.

Returning now again to a discussion of the different functioning of the four areas 52, 54, 56 and 58 of the memory map 50 introduced previously herein, it will be remembered that, in the best presently known embodiment 10 of the present invention, the program language accelerator core 10 contains 64

words in its hardware intelligent stack 12. This address space is divided into the four major areas 52, 54, 56 and 58, each of which allows different operations to be executed by reading or writing to an address therewithin. Regarding the first area 52 of the memory map 50, this area acts as one skilled in the art would expect the memory map 50 to behave were this the only area of the memory map - that is, if there were a one to one correlation between the addresses of the memory map 50 and the cache 38. The first area 52 of the memory map 50 is provided to allow read and write access to any of the hardware stack registers (64 32-bit registers) as though they were random access memory.

Regarding the second area 54 of the memory map 50, the registers in this area control the operation of the program language accelerator core 10. These registers have read and write access. This area contains four special write-only locations, also. Two of the write only locations are used for variable operations and two are used for context switching. Addressing any of these registers is done via the low address bits of the native CPU 16. Table 2, below is a listing of the applicable registers within the second area 54 of the memory map 50.

TABLE 2

Address	Register	Register or Function
0	SP	Stack Pointer.
1	BOSP	Bottom of Stack Pointer.
2	WLIMIT	Upper limit in main memory where the stack can be written to.
3	RLIMIT	Lower limit in memory where the stack can be read.
4	VREG	Variable Address Register. This location can be written or read for testing purposes. It is automatically written with the address of the last accessed variable.
5	SWAPINSIZE	Swap-in Size. This register controls how many words will be read in when a swap-in DMA cycle is started.
8	VLOAD	Variable Load. This register has write only access. When this special location is written, the data bus has the absolute address of a local variable that should be pushed on to the top of the stack. A DMA cycle is started if the variable is not in the cache. If the variable is in the cache, one additional cycle is taken to transfer the contents to the top of the stack.
9	VSTORE	Variable Store. This register has

		write only access. When this special location is written, the data bus has the absolute address of local variable that should get the value from the top of the stack. A DMA cycle is started if the variable is not in the cache. If the variable is in the cache, one additional cycle is taken to transfer the contents to the top of the stack
14	SWAPIN	Swap-in. This register has write only access. When this special location is written, the value on the data bus is ignored and a block mode DMA cycle is started to fill the cache from main memory. The number of word read depends on the value of the SWAPINSIZE register, so this may be tuned for a specific state of a thread
15	SWAPOUT	Swap-out. This register has write only access. When this special location is written, the value on the data bus is ignored and a block mode DMA cycle is started to flush the cache to main memory. The number of word read depends on the value of SP and BOSP

Regarding the third area 56 of the memory map, this area is used for pushing values or constants to the stack or popping values from the stack. The operation to be performed is determined by the low address bits of the processor (the select byte 62). That is, the address determines the operation to be performed. These functions are listed below in table 3. One skilled in the art will recognize that, in some instances, the value of data provided by the native CPU 16 to the program language accelerator core 10 will be irrelevant, since the operation is performed using a constant value.

TABLE 3

Address	Operation	Operation Description
0	PUSHPOP	Pushes the value on the data bus to the stack (write operation) or pops a value from TOS to the data bus (read operation).
2	ICONSTm1	Write only location. Pushes a constant integer (-1)
3	ICONST0	Write only location. Pushes a constant integer 0

4	ICONST1	Write only location. Pushes a constant integer 1
5	ICONST2	Write only location. Pushes a constant integer 2
6	ICONST3	Write only location. Pushes a constant integer 3
7	ICONST4	Write only location. Pushes a constant integer 4
8	ICONST5	Write only location. Pushes a constant integer 5
11	FCONST0	Write only location. Pushes a constant float 0.0
12	FCONST1	Write only location. Pushes a constant float 1.0
13	FCONST2	Write only location. Pushes a constant float 2.0

Regarding the fourth area 58 of the memory map 50, this area is used to initiate arithmetic operations on the value at the Top-Of-Stack. The value at the top of the stack is replaced with the result of an arithmetic operation between value on the data bus the current value at the Top-Of-Stack. The arithmetic operation to be performed is determined by the low address bits of the processor (the select byte 62). All of these operations are performed on integer values (32-bit integers). These functions are listed in table 4, below.

TABLE 4

Address	Operation	Arithmetic Operation Description
16	IADD	Write only location. Adds the value at the top of the stack to the value on the data bus, replacing the value at the top of the stack.
17	ISUB	Write only location. Subtracts the value on the data bus from the value at the top of the stack, replacing the value at the top of the stack.
18	INEG	Write only location. Subtracts the value at the top of the stack from 0, replacing the value at the top of the stack. Ignores the value on the data bus.
19	IOR	Write only location. Performs a bit-wise OR on the value at the top of the stack with the value on the data bus, replacing the value at the top of the stack.
20	IAND	Write only location. Performs a bit-wise AND on the value at the

		top of the stack with the value on the data bus, replacing the value at the top of the stack.
21	IEXOR	Write only location. Performs a bit-wise Exclusive-OR on the value at the top of the stack to the value on the data bus, replacing the value at the top of the stack
22	IINCR	Write only location. Adds 1 to the value at the top of the stack, replacing the value at the top of the stack. Ignores the value on the data bus.

Referring now to the value push operation 80 shown in Figure 6, when the program language accelerator software 34 has translated and optimized the Java™ code regarding a value push operation, and it is time for such operation to be executed, the value will be written to the location "pushpop" (see Table 3) in operation 80a. In an operation 80b, the address is decoded (by the decoder 46 - Figure 3) the value is so directed. Then, in an operation 80c the value written from the data bus (Figure 2) is written into the hardware stack (the cache 38 - Figure 3) at the location pointed by its TOS register, and the TOS is incremented. If the hardware stack (cache 38) approaches overflow, as determined in a decision operation 80d, then the smart DMA controller 14 is initiated to save a portion of the content of the cache 38 to the memory 30 (Figure 2) in an operation 80e.

Referring now to the value pop operation 82 shown in Figure 7, when the program language accelerator software 34 has translated and optimized the Java™ code regarding a value pop operation, and it is time for such operation to be executed, the read command will be directed to the appropriate location in operation 82a. In an operation 82b, the address is decoded (by the decoder 46 - Figure 3). Then, in an operation 82c the value read (popped) from the cache 38 (Figure 3) and the TOS pointer is decremented. The value is sent to the data bus (Figure 2) in an operation 82d. If this leaves the hardware stack (cache 38) in an underflow condition, as determined in a decision operation 82e (that is, if the cache 38 has reached a predetermined level of non-use), then the smart DMA controller 14 is initiated to restore a portion of the content of the cache 38 from the memory 30 (Figure 2) in an operation 82f.

Referring now to the constant push operation 84 shown in Figure 8, when the program language accelerator software 34 has translated and optimized the Java™ code regarding a constant push operation, and it is time for such operation to be executed, the write command will be directed to the appropriate location in operation 84a. In an operation 84b, the address is decoded (by the decoder 46 - Figure 3). Then, in an operation 84c the constant value dictated by the particular address selected is written (pushed) into the hardware stack (the cache 38 - Figure 3) at the location pointed by its TOS

register, and the TOS is incremented. If the hardware stack (cache 38) approaches overflow, as determined in a decision operation 84d, then the smart DMA controller 14 is initiated to save a portion of the content of the cache 38 to the memory 30 (Figure 2) in an operation 84e.

Referring now to the arithmetic operation 86 shown in Figure 9, when the program language accelerator software 34 has translated and optimized the Java™ code regarding a particular arithmetic operation, and it is time for such operation to be executed, the write command will be directed to the appropriate location in operation 86a. Note that exactly what that appropriate location might be will be dictated by the particular arithmetic operation that is to be performed, as listed previously herein in Table 4. In an operation 86b, the address is decoded (by the decoder 46 - Figure 3) and the corresponding data is fetched from that data bus 22 (Figure 2). Then, in an operation 86c the arithmetic operation corresponding to the selected address is performed on the value at the top of stack using the value written from the data bus (Figure 2) and the result is written into the hardware stack (the cache 38 - Figure 3) at the location pointed by its TOS register.

In a variable store operation 90 (Figure 11), when the program language accelerator software 34 has translated and optimized the Java™ code regarding a variable store operation, and it is time for such operation to be executed, a write will be directed to the dedicated memory location corresponding to the store operation in the intelligent stack 12 in operation 90a. The value written to the data bus 22 should be the absolute memory address of the required local variable to be stored. In an operation 90b, the address is decoded (by the decoder 46 - Figure 3). Then, if the required variable is in the stack (as determined in a decision operation 90c) the variable value is read from the TOS and stored to its required address and the top of stack is decremented. If the required variable is not in the stack, as determined in the decision operation 88c, then the smart DMA controller 14 is initiated to store the variable value from the top of stack and decrement the TOS in an operation 90e. If the hardware stack (cache 38) approaches underflow, as determined in a decision operation 90f, then the smart DMA controller 14 is initiated to restore the stack content from the main memory 30.

In a variable load operation 88 (Figure 10), when the program language accelerator software 34 has translated and optimized the Java™ code regarding a variable load operation, and it is time for such operation to be executed, a write will be directed to the dedicated memory location in the intelligent stack 12 in operation 88a which is dedicated to the variable store operation. The value written to the data bus 22 should be the absolute memory address of the required local variable to be stored. In an operation 88b, the address is decoded (by the decoder 46 - Figure 3). Then, if the required variable is in the stack (as determined in a decision operation 88c) the variable value is read from the cache 38 and placed at the top of stack in an operation 88d - and the TOS is incremented. If the required variable is not in the stack, as determined in the decision operation 88c, then the smart DMA controller 14 is initiated to load the variable value to the top of stack and increment the TOS in an operation 88e. If the hardware stack (cache 38) approaches overflow, as determined in a decision operation 88f, then the

smart DMA controller 14 is initiated to transfer the stack content to the main memory 30 from the hardware stack (cache 38).

Various modifications may be made to the invention without altering its value or scope. For example, although the inventive program language accelerator core 10 and associated program language accelerator software 34 are described herein as being optimized for use with the Java™ program language, the principles involved are equally applicable for use with other program languages, particularly if such languages might be developed primarily for use with stack based systems.

As previously mentioned, yet another likely modification would be to implement the program language accelerator core as a device physically distinct from the CPU chip 18 such that it could more readily be added to existing systems or existing system designs.

#### **INDUSTRIAL APPLICABILITY**

The inventive program language accelerator core 10 and the related program language accelerator software 34 are intended to be widely used for the real time execution of Java™ code in conjunction with processors which are otherwise optimized for executing programs written in languages other than Java™. As can be appreciated in light of the above description, the program language accelerator core 10 uses an entirely new concept in that the program language accelerator software, when interpreting the Java™ code for execution in the native code of the native CPU 16 will cause certain operations to be directed to certain virtual memory addresses such that the operation is automatically accomplished by the intelligent stack 12. That is, the intelligent stack 12 will know what operation is to be performed and will perform it based solely on the address to which the data is written in the memory map. This will save from one to several clock cycles per operation where this feature is invoked. Thereby, the speed of execution of Java™ code will be greatly enhanced without burdening the computer 20 with the running of a virtual machine, or the like, in the background.

Since the program language accelerator core 10 of the present invention may be readily produced and integrated into existing designs for systems and devices, and since the advantages as described herein are provided, it is expected that it will be readily accepted in the industry. For these and other reasons, it is expected that the utility and industrial applicability of the invention will be both significant in scope and long lasting in duration.

All of the above are only some of the examples of available embodiments of the present invention. Those skilled in the art will readily observe that numerous other modifications and alterations may be made without departing from the spirit and scope of the invention. Accordingly, the above disclosure is not intended as limiting and the appended claims are to be interpreted as encompassing the entire scope of the invention.

**WHAT IS CLAIMED IS**

1. A computer system having a CPU and a memory, comprising:  
a plurality of memory addresses wherein a selected memory address is allocated to a particular operation such that when the CPU writes data to said selected memory address then that particular operation is performed on that data without further intervention from the CPU.
2. The computer system of claim 1, and further including:  
an arithmetic logic unit for performing said particular operation.
3. The computer system of claim 1, and further comprising:  
a translator for translating a program code into a native language code, and further for directing the particular operation to said selected memory address.
4. The computer system of claim 4, wherein:  
the program code is Java™.
5. A program language accelerator for operation with a central processing unit, comprising:  
a translator for translating the program language into a native code, wherein selected operations are assigned to particular address locations such that when data is written to said particular address locations then specific operations associated with such address locations are performed on the data.
6. The program language accelerator of claim 5, wherein:  
the program language to be accelerated is Java™.
7. The program language of accelerator of claim 5, and further comprising:  
a dedicated hardware stack.
8. The program language accelerator of claim 5, wherein:  
said selected operations include arithmetic operations.
9. The program language accelerator of claim 8 and further including:  
an arithmetic logic unit for accomplishing said selected operations independent of the central processing unit.
10. A method for accelerating the execution of a computer code, comprising:



providing a plurality of memory locations such that data written to at least some of said memory locations will have an operation performed thereon without further intervention.

11. The method of claim 10, wherein:

at least some of said plurality of memory locations are directed to a dedicated hardware stack.

12. The method of claim 10, and further including:

interpreting the computer code such that data on which the operation will be performed is written to a memory location associated with the operation.

13. The method of claim 12, wherein:

the computer code is Java™.

14. The method of claim 12, wherein:

the interpreting is accomplished by software residing in a memory when the computer code is loaded into the memory.

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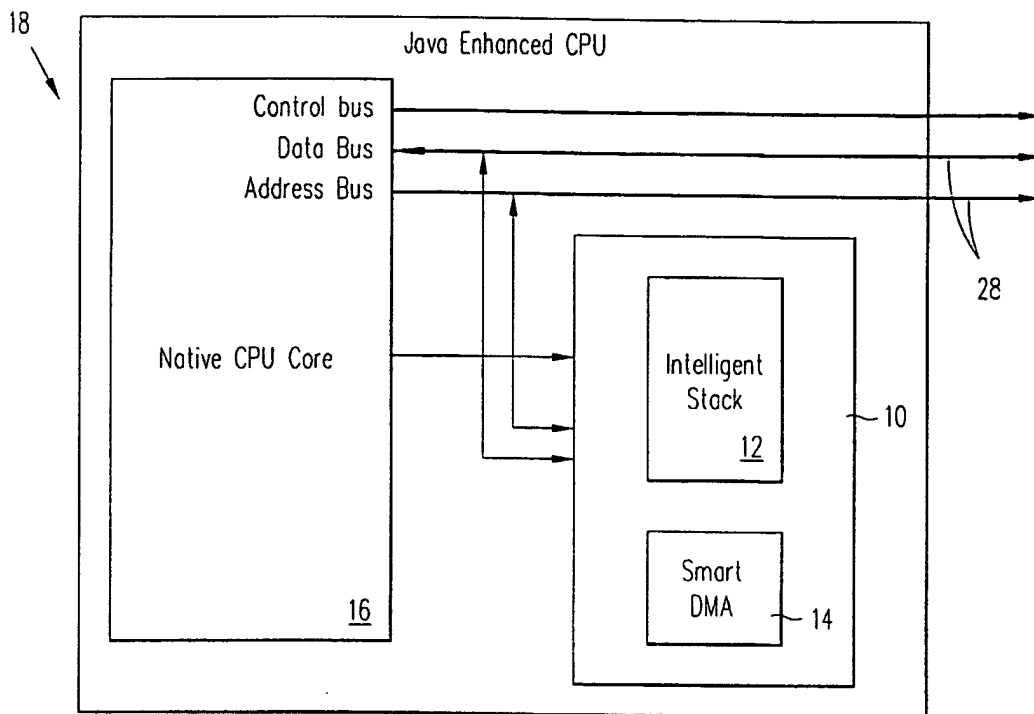


FIG. 1

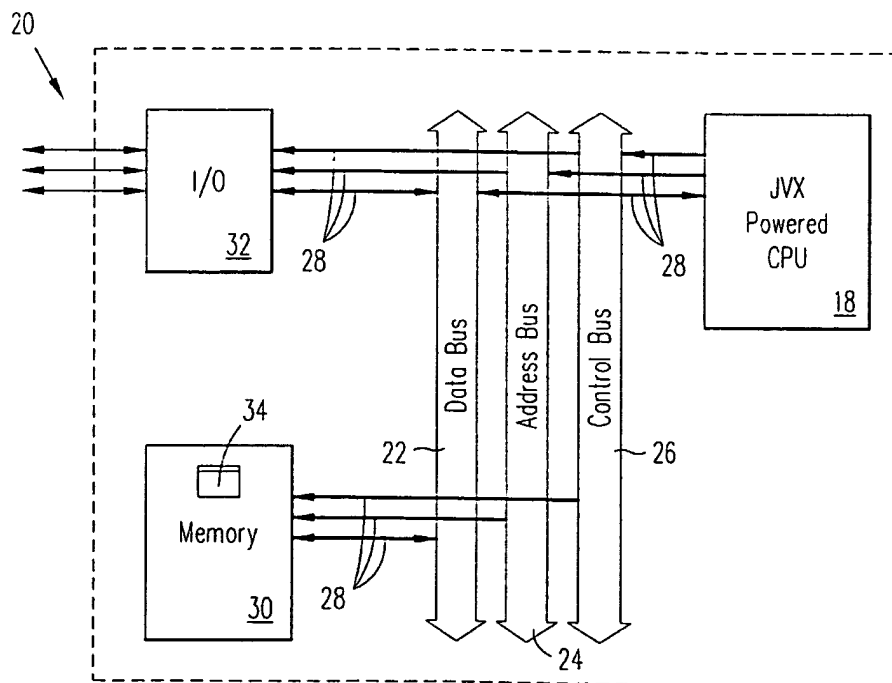


FIG. 2

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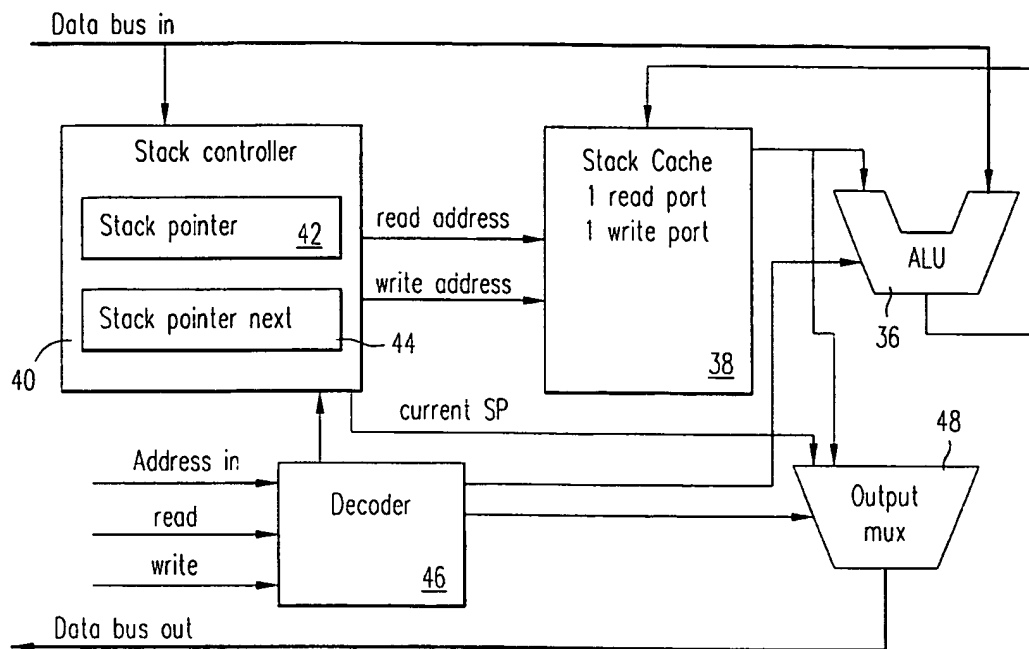


FIG. 3

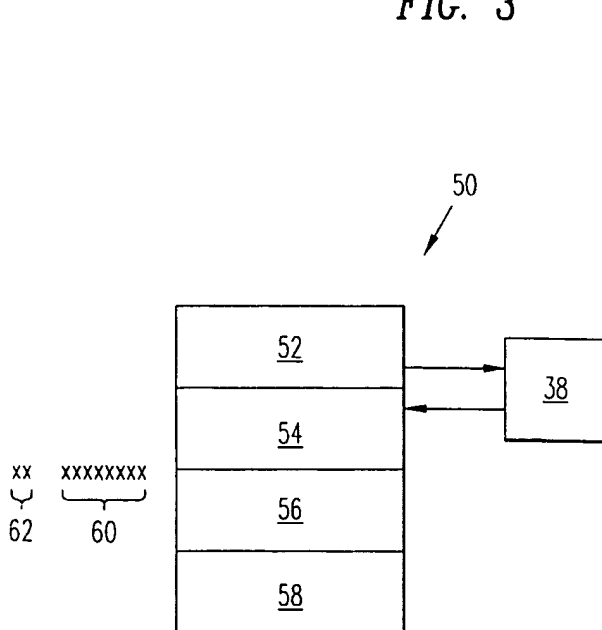


FIG. 4

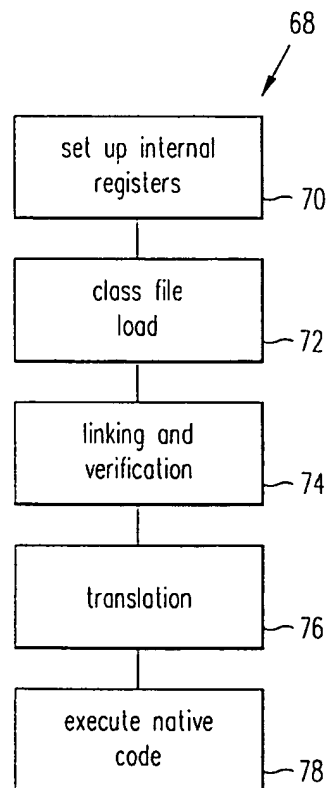


FIG. 5

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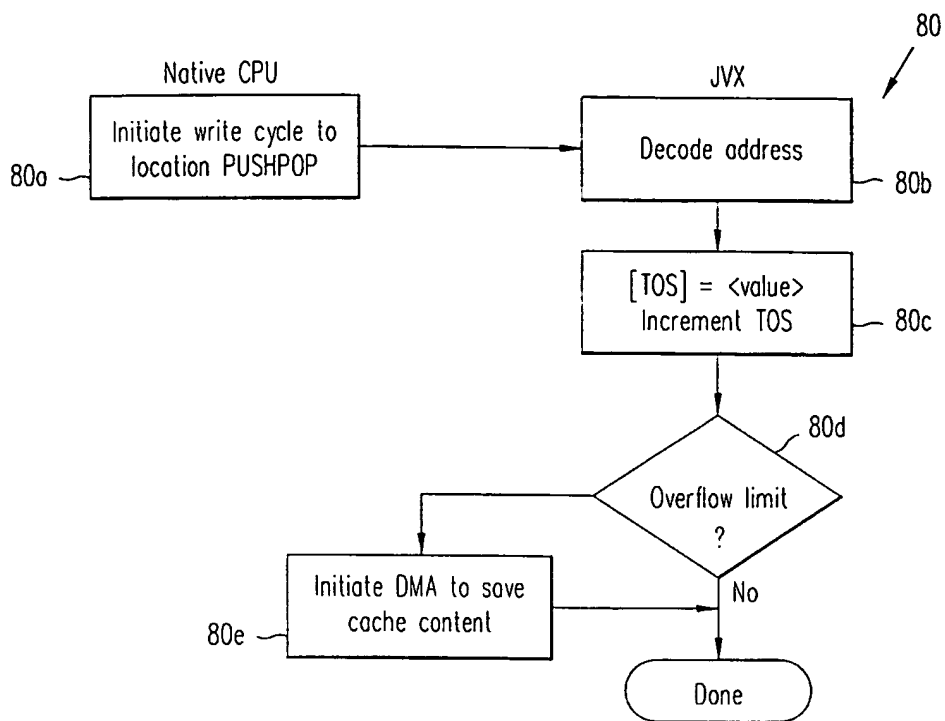


FIG. 6

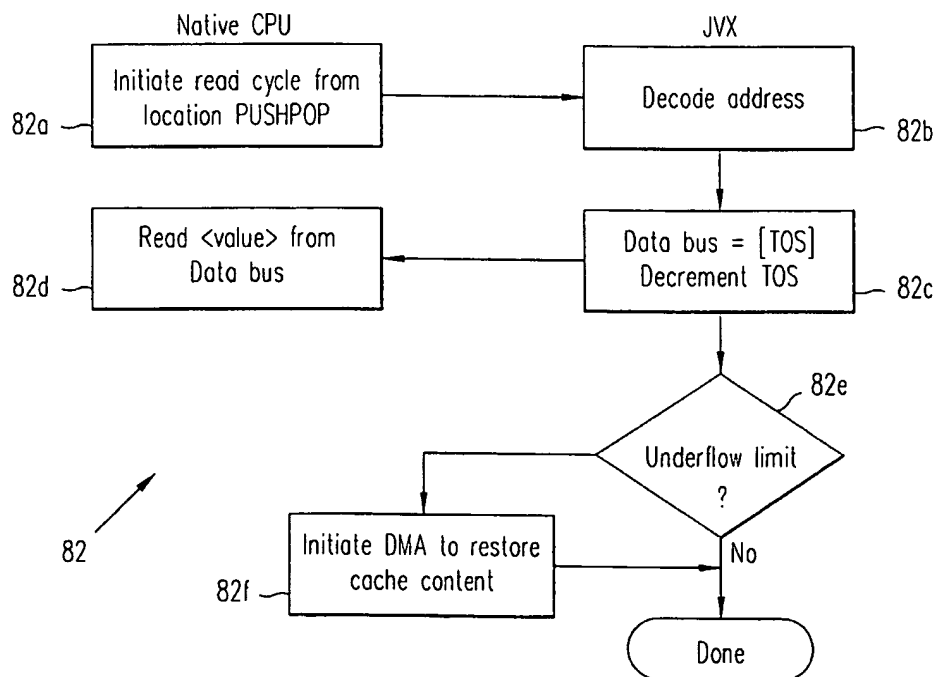


FIG. 7

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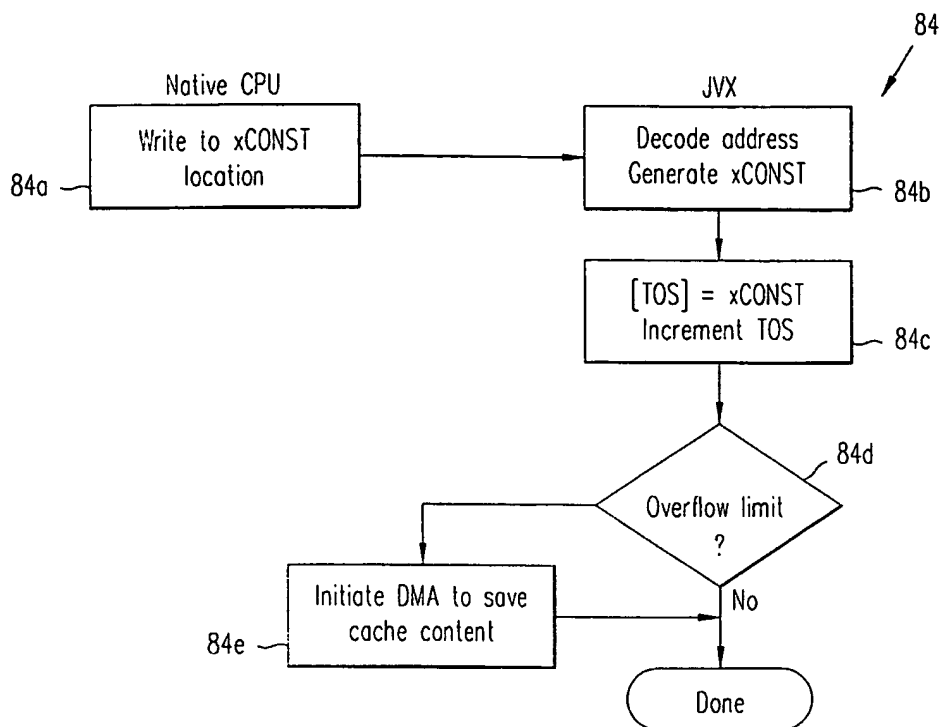


FIG. 8

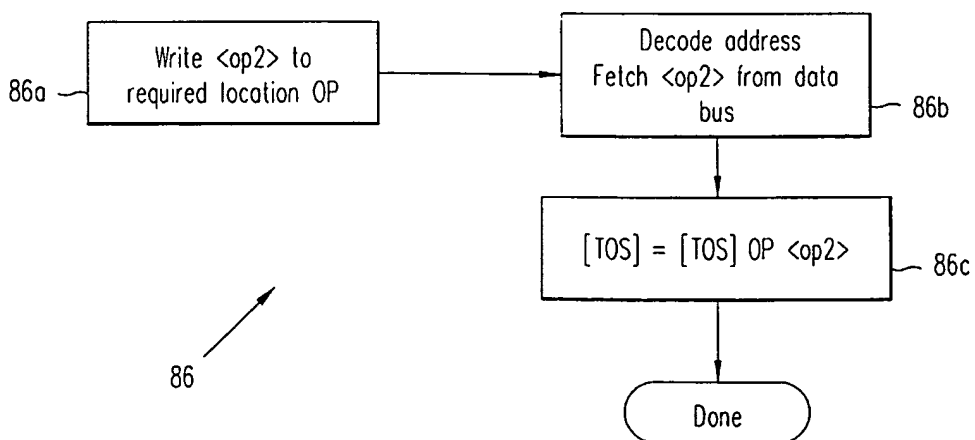
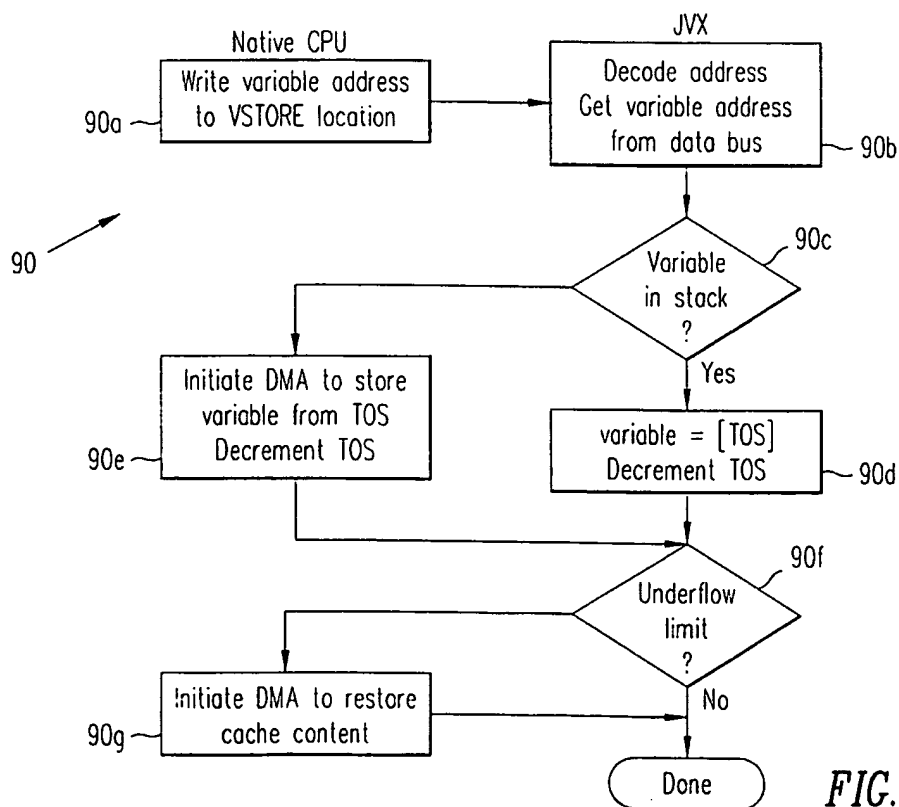
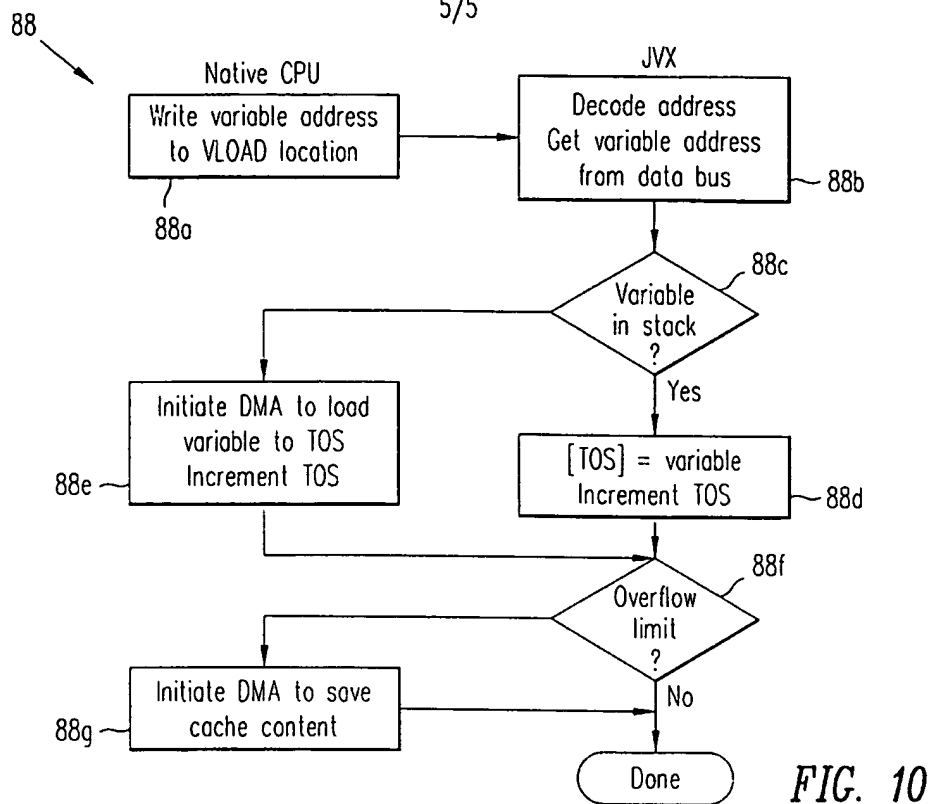


FIG. 9

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# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US97/20980

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(6) :G06F 11/00 US CL :395/705, 706, 709, 406, 381, 800.01 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) U.S. : 395/705, 706, 709, 406, 381, 800.01 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) APS, COMPUTER SELECT, IEEE		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CASE. B. Implementing the Java Virtual Machine; Java's Complex Instruction Set Can Be Built in Software or Hardware Microprocessor Report March 1996. Vol 10, No. 4. pages 12-18, especially pages 12 and 13.	1-14
Y	WAYNER. P. Sun Gambles on Java Chips Byte November 1996. Vol 21. No. 11. pages 79-85, especially page 82.	1-14
Y	US 4,205,370 A (HIRTLE) 27 May 1980, see entire document.	1-14
Y	US 4,674,089 A (PORET et al) 16 June 1987, see entire document.	1-14
Y	US 5,442,777 A (NAKAJIMA et al) 15 August 1995, see entire document.	1-14
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *A* document defining the general state of the art which is not considered to be of particular relevance *E* earlier document published on or after the international filing date *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *O* document referring to an oral disclosure, use, exhibition or other means *P* document published prior to the international filing date but later than the priority date claimed *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art *A* document member of the same patent family	
Date of the actual completion of the international search 11 FEBRUARY 1998		Date of mailing of the international search report 14.04.1998
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer MICHAEL RICHEY Telephone No. (703) 305-9669

**INTERNATIONAL SEARCH REPORT**International application No.  
PCT/US97/20980**C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,126,541 A (SHINAGAWA) 30 June 1992, see entire document.	1-14